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# Priming T2 in a visual and auditory attentional blink task

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Participants performed an attentional blink (AB) task including digits as targets and letters as distractors within the visual and auditory domains. Prior to the rapid serial visual presentation, a visual or auditory prime was presented in the form of a digit that was identical to the second target (T2) on 50% of the trials. In addition to the "classic" AB effect, an overall drop in performance on T2 was observed for the trials on which the stream was preceded by an identical prime from the same modality. No cross-modal priming was evident, suggesting that the observed inhibitory priming effects are modality specific. We argue that the present findings represent a special type of negative priming operating at a low feature level.

Capacity limitations in the visual system become evident when a vast amount of information needs to be processed within a limited period of time. A classic example of such a capacity limitation is the *attentional blink* (AB) deficit (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). An AB occurs when people have to report two target items (e.g., words or single characters) presented among distractors in a *rapid serial visual presentation* (RSVP), in which items are presented in succession at a high rate (e.g., 10 items per second). People are accurate in reporting the *first target* (T1) but often fail to report the *second target* (T2). The AB is most severe when T1 and T2 are presented close together in time (within 200–500 msec) but gradually disappears as the time period between the targets becomes longer.

One of the early models explaining the AB effect is the *two-stage* model of Chun and Potter (1995). As its name implies, this model divides target detection into two stages: In the first stage, relevant features of the target are detected, and in the second, the target is consolidated into *short-term memory* (STM). The model states that the AB deficit is based on a capacity limitation that occurs during consolidation of T2 into STM (Jolicœur & Dell'Acqua, 1998). The AB occurs because resources used during consolidation of T1 are not available at the time when consolidating T2 is necessary. This results in a bottleneck in the transfer of sensory codes to STM.

According to the two-stage model, consolidation is necessary for reporting T2. To get a better understanding of the process underlying the AB, it is important to know whether or not prior knowledge already consolidated into STM has an influence on the AB. In other words, what happens to T2 performance when an item identical to T2 has already been shown and consolidated into STM prior to the presentation of T2? The classic study by Jacoby and Dallas (1981) showed that identification of an item (e.g., a word) improves as a result of prior exposure to a similar or identical item. This effect is called *repetition priming*, and on the basis of the effect repetition priming has on performance, an improvement of T2 performance can be expected.

However, Akyürek and Hommel (2005) found an overall performance drop on T2 in an AB task when participants held in memory characters from the same class as T2. In this paradigm, participants had to memorize in each trial a number of characters (letters, digits, or symbols), displayed prior to the RSVP stream, which they had to report back afterward. Their performance on the AB task became worse as the STM load became higher and as the STM content became more related to the targets (letters, digits, or symbols) in the AB task. Interestingly, the drop in performance did not interact with the AB and was constant over the lag condition. Another study (Nieuwenstein, Johnson, Kanai, & Martens, 2007) showed a similar drop in T2 performance when an STM set contained an item identi-

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cal to T2, as compared with an STM set without identical items. Both studies showed that when an item identical to or from the same class as T2 is already consolidated in STM, performance on T2 drops. Thus, performance on T2 seems to suffer because of competition between related items already stored in STM (Akyürek & Hommel, 2005), whereas the AB deficit itself is assumed to be the result of capacity limitations during the consolidation of items into STM (Jolicœur & Dell'Acqua, 1998). Nieuwenstein et al. explained this effect as a failure in attributing the same item information to both the STM and AB tasks. They referred to the additional failure in reporting T2 when this item is already coupled to a different task—in this case, an STM task—as "cross-talk repetition amnesia." Both Akyürek and Hommel and Nieuwenstein et al. concluded that the additional drop in T2 performance does not occur during the consolidation stage, but instead seems to reflect interference in STM and to be based on a different process than the AB.

The cross-talk repetition amnesia hypothesized by Nieuwenstein et al. (2007) is in line with the *episodic retrieval* model (DeSchepper & Treisman, 1996; Neill & Mathis, 1998; Neill, Valdes, Terry, & Gorfein, 1992), which is used to explain a process called *negative priming* (NP). The label *NP* is broadly used for perceptual inhibitory processes (Neill & Mathis, 1998; Rothermund, Wentura, & De Houwer, 2005; Tipper, 1985; Wood & Milliken, 1998). The classical NP paradigm (Tipper, 1985) consists of prime and probe trials, each containing a target and a distractor item. When a distractor item that needs to be ignored in the prime trial becomes a target item in a subsequent probe trial, the response to this target tends to be slower. The *inhibition* model of NP (Houghton, Tipper, Weaver, & Shore, 1996; Tipper, 1985; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991) explains this effect by inhibition of a to-be-ignored item. When the inhibited item becomes a target, the activation threshold of the item is higher than that of uninhibited targets. The episodic retrieval theory of NP (DeSchepper & Treisman, 1996; Neill & Mathis, 1998; Neill et al., 1992), on the other hand, states that the representation of an item is stored along with an "action tag" indicating what to do with the item. This action tag could involve the coupling to a task, as suggested by cross-talk repetition amnesia. In the case of NP, a distractor item stored with a no-response tag creates conflict when it becomes a target item to which participants have to respond.

In the present study, participants were presented with an RSVP stream of letters containing two digits as targets. Prior to the RSVP stream, a prime was presented that was either identical or not identical to T2, but which always belonged to the same class (digits) as the target. Instead of an additional memory task, as was used by Akyürek and Hommel (2005), a single prime was used. The question we addressed was whether a performance reduction would show up, similar to the one reported in experiments that used an additional memory task, or whether a positive enhancement effect would show up, due to repetition priming. To anticipate the results, our Experiment 1 showed an inhibitory effect on T2 performance when the target was primed by a physically identical item, which is in line with previous work (Akyürek & Hommel, 2005; Nieuwenstein et al., 2007). Three additional experiments were conducted to investigate whether this effect could be explained in terms of NP.

A second objective of this study was to determine whether this effect on T2 performance is restricted to the visual domain. On the basis of the previous priming (Graf, Shimamura, & Squire, 1985) and NP (Buchner, Zabal, & Mayr, 2003) literature, it is quite feasible that similar effects exist in auditory, and even cross-modal, conditions. To answer this question, two additional experiments were conducted using an auditory or a visual serial stream preceded by an auditory prime.

## EXPERIMENT 1
## Visual–Visual Priming

In Experiment 1, participants were presented with an RSVP stream containing two target digits among distractor letters. Prior to the RSVP stream, a prime was presented that was either identical or not identical to T2. The participants had to report whether the target digits presented within the RSVP stream were odd or even.

### Method

**Participants**. Twelve students of Vrije Universiteit Amsterdam (9 female, 3 male; mean age 22.3 years, age range 19–33) took part in the experiment. All had normal or corrected-to-normal vision. The participants were informed beforehand about the experimental procedure and were naive as to the purpose of the experiment.

**Design and Stimuli**. This experiment had a $2 \times 4$ design with the factors prime (prime $\neq$ T2, prime $=$ T2) and lag (1, 2, 3, or 8). The RSVP stream contained 20 elements, each of which was presented for 16 msec, followed by an interstimulus interval (ISI) of 80 msec. T1 was presented at Position 7, 8, or 9 in the RSVP stream, and T2 was positioned at a lag of 1, 2, 3, or 8 after T1. All T1 and T2 position combinations occurred equally often, in a random order. Prior to the RSVP stream, a prime was displayed for 1.5 sec, followed by a fixation cross for 200 msec, as shown in Figure 1. The prime was displayed in all trials; it was identical to T2 on 50% of the trials and was never identical to T1. The digits 1–9 (5 excluded) were used for the prime, T1, and T2, and the distractors were capital letters of the alphabet (with the letters *I* and *X* excluded). All characters were displayed at the center of the screen in dark gray, 48-point Geneva font (0.63 $cd/m^2$, 1.4º width, 1.6º height) on a gray (9.34 $cd/m^2$) background. During practice, all characters were displayed in black in order to familiarize participants with the task.

**Apparatus and Procedure**. The participants were seated in a dimly lit cabin approximately 80 cm from a computer screen (17-in., 120-Hz). The experiment was run in E-Prime 1.1 (SP3). The task instructions were presented onscreen, after which the participants started with a practice block of 48 trials. The participants were instructed to look at the prime digit, but also that the digit was irrelevant for the task and did not need to be responded to. After each block, the participants received feedback on their overall performance. The experiment consisted of six blocks containing 48 trials each. The participants had to respond (unspeeded) to T1 and T2 sequentially, by pressing the "o" key for *odd* or "e" key for *even* on a QWERTY keyboard.

### Results

For all analyses, a significance level of $p < .05$ was used, and $MS_e$ and $p$ values were Greenhouse–Geisser adjusted when required. Two separate repeated measurements ANOVAs were conducted for performance on T1 and for performance on T2, given that T1 was correctly identified.

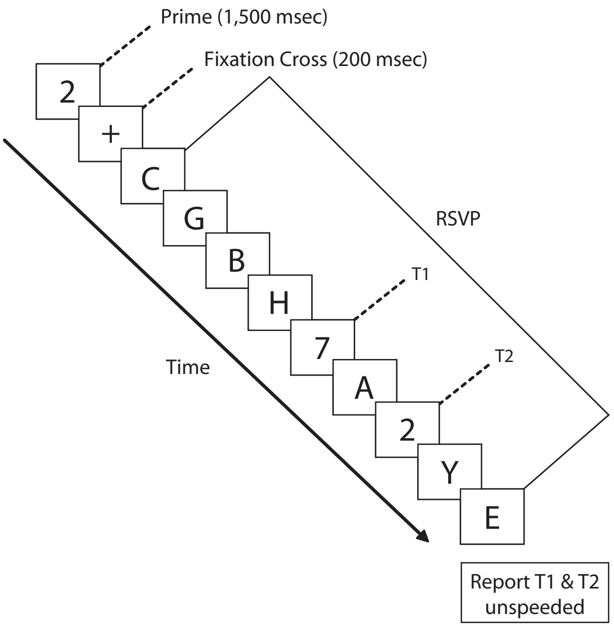


**Figure 1. Schematic representation of the paradigm used. Participants received a rapid serial visual presentation (RSVP). The task was to identify the two targets (T1 and T2), which were digits, and to report, unspeeded and in order of appearance, whether they were odd or even. Prior to the RSVP stream, a prime was presented for 1.5 sec. In 50% of the trials, the prime was identical to T2.**

Prime and lag were within-subjects variables. Figure 2 shows the mean percentages correct for T2 given that T1 was correctly identified, as a function of lag and prime.

**T1 accuracy**. Overall, performance was 91% correct. For the prime = T2 condition, the percentage-correct scores for T1 for lags 1, 2, 3, and 8 were 88%, 91%, 92%, and 96%, respectively. In the same order, the results for the prime ≠ T2 condition were 83%, 93%, 92%, and 95%. The main effect of prime failed to reach significance ($F < 1$), but performance did vary with lag [$F(3,33) = 10.523$, $MS_e = .006$, $p < .005$], and the two-way interaction between prime and lag was significant [$F(3,33) = 3.401$, $MS_e = .003$, $p < .05$]. The interaction was further analyzed by pairwise *t* tests between the prime conditions for each lag (1–3 and 8), which only revealed a significant effect for lag 1 ($p < .05$). The main effect of lag was also further analyzed by pairwise *t* tests between lags. These results only showed a significant effect for lag 1 relative to lag 2 ($p < .05$).

**T2 accuracy**. Performance varied with lag [$F(3,33) = 16.357$, $MS_e = .023$, $p < .001$]. There was also a significant effect of prime [$F(1,11) = 12.368$, $MS_e = .005$, $p < .01$], resulting in an overall drop in performance when T2 was primed (84%) as compared with when it was not primed (89%). The two-way interaction between prime and lag failed to reach significance [$F(3,33) = 1.525$, $MS_e = .004$, $p = .236$].

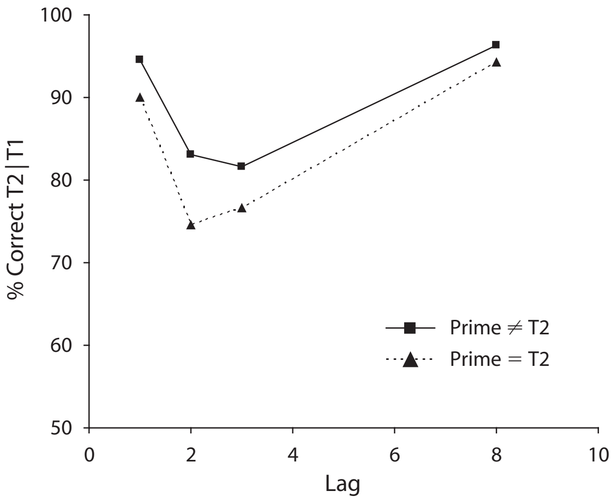


**Figure 2. Results of Experiment 1, in percentages correct, for T2 given T1 correct (T2 | T1) as a function of lag and prime.**

## Discussion

Priming of T2 did not affect T1 performance, with the exception of at the first lag. The drop in performance on T1 for lag 1 is similar to the effect reported by Akyürek and Hommel (2005), as well as to that reported by Potter, Staub, and O'Connor (2002). The researchers explained this effect in terms of competition between two succeeding targets when they are selected from the same set of characters (digits). This competition seems to be strongest when T2 is not identical to the prime, as shown by the observed interaction. Another explanation for this effect could be that participants remembered T1 and T2 in the incorrect order. At the end of the trial, participants had to report whether the two targets (T1 and T2) were odd or even. This had to be done unspeeded and in the correct order. Thus, not only the targets themselves had to be remembered, but also the order of their appearance. When targets are presented close in time, as is the case for lag 1, and both characters are from the same character class, an order judgment can become difficult, resulting in a drop in T1 performance on lag 1. Note that this effect is not apparent in the scores, since only the scores of T2 given T1 correctly identified are shown.

The typical U-shaped drop in T2 performance from lag 1 to lag 8 shown in Figure 2 reflects a standard AB effect (Raymond et al., 1992). The results further show an overall inhibitory effect of prime on T2 performance and no interaction between prime and lag. These results are in line with earlier work (Akyürek & Hommel, 2005; Nieuwenstein et al., 2007) and show that when an item identical to T2 is previously consolidated, it becomes harder for participants to correctly identify T2.

In this experiment, participants were instructed to look at the prime but were not required to actively maintain it. Unlike in a typical NP paradigm, in which participants have to ignore the prime in order to make the appropriate response, in the present experiment observers were asked to attend to the prime but did not have to give an overt response. However, even though we did not instruct participants to do so, we cannot rule out that the participants actively suppressed the prime as a strategy to enhance their task performance. If participants *did* actively suppress the prime, this would be consistent with the idea that the drop in performance during the AB task is the result of inhibition.

According to the inhibition model, if participants actively maintained a prime, one would not expect a drop in performance for T2 (since there would be no need for inhibition); if anything, on the basis of Tipper's (1985) results, one would expect a performance benefit for T2. Experiment 2 was basically a replication of Experiment 1, but now we ensured that participants actively maintained the prime in STM.

## EXPERIMENT 2
## Memorizing the Prime

In this experiment, participants were instructed to memorize the prime instead of just attending to it. To make sure that they followed the instructions, we added a few so-called *prime recall trials*. In these trials, participants had to report the identity of the prime after presentation of the RSVP stream. Because the prime was now actively maintained in STM, we expected enhanced T2 performance when the prime and T2 were identical (Tipper, 1985).

### Method

The present experiment was identical to Experiment 1, except that participants were instructed to memorize the prime presented in each trial. Additional prime recall trials were included, which constituted 20% of the trials. These trials were identical to the other trials, with the exception that a different response had to be given: Instead of reporting the targets, a number word (e.g., the word *eight*) appeared onscreen, and participants were asked to indicate by pressing "j" for *yes* and "n" for *no* whether the number word displayed was the same as or different from the prime digit kept in memory. Twelve new students (6 female, 6 male; mean age 23.3 years, age range 17–37) participated in the experiment.

### Results

On average, participants scored 98% correct on the prime recall trials. This provides a strong indication that they actively observed the prime and maintained it in STM during a trial.

**T1 accuracy**. T1 was correctly identified on 87% of the trials. For the prime = T2 condition, T1 performance at lags 1, 2, 3, and 8 was 80%, 90%, 88%, and 92%, respectively. In the same order, the results for the prime $\neq$ T2 condition were 76%, 88%, 91%, and 93%. There was no significant effect of prime on T1 performance ($F < 1$), but performance did vary significantly with lag [$F(3,33) = 9.336$, $MS_e = .022$, $p < .004$], and there was no significant interaction between prime and lag [$F(3,33) = 1.073$, $MS_e = .005$, $p = .363$].

**T2 accuracy**. The average scores for each condition are shown in Figure 3. T2 given T1 correct varied with lag [$F(3,33) = 20.381$, $MS_e = .029$, $p < .001$], indicating an AB effect. There was a significant main effect of prime on T2 performance [$F(1,11) = 9.308$, $MS_e = .007$, $p < .05$] resulting in poorer performance when T2 was primed (78%) than when it was not primed (83%). The two-way interaction between prime and lag was significant [$F(3,33) = 4.299$, $MS_e = .008$, $p < .05$]; a further analysis by two-tailed $t$ tests for each lag (1, 2, 3, and 8) only showed a significant effect for lag 2 ($p < .05$).

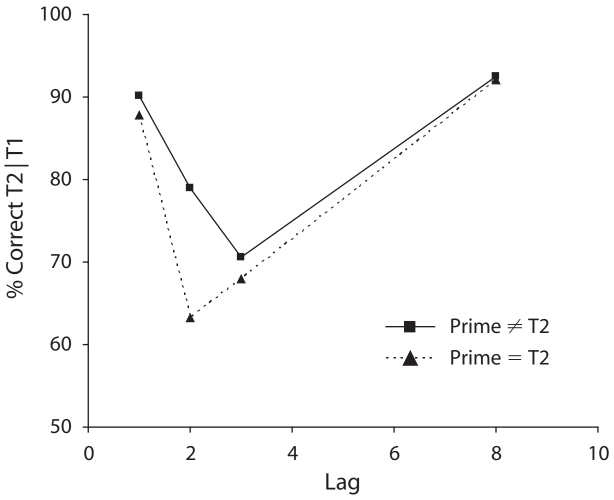


**Figure 3. Results of Experiment 2, in percentages correct, for T2 given T1 correct (T2 | T1) as a function of lag and prime.**

Comparing overall T2 | T1 performance between Experiments 1 and 2, by means of one-sided independent-samples $t$ tests, revealed a significant ($p = .0265$) drop in performance for Experiment 2 relative to Experiment 1.

### Discussion

The present experiment replicated and extended the findings of Experiment 1 by showing an inhibitory effect of prime on T2 performance, even when it was ensured that the prime was stored in STM. Thus, contrary to the predictions of the inhibition model of NP (Houghton et al., 1996; Tipper et al., 1991), in the present paradigm actively maintaining the prime did not lead to facilitation. Note that these results are in line with earlier studies that have shown a similar drop in T2 performance when items related to T2 were actively maintained in STM (Akyürek & Hommel, 2005; Nieuwenstein et al., 2007). However, in contrast to Experiment 1, the present results showed an interaction between prime and lag, indicating a clear priming effect for lag 2 but not for the other lags.

It is likely that this interaction was due to the fact that the memory task had an overall detrimental effect on performance. Regardless of whether the prime matched T2 or not, performance at lags 2 and 3 was much worse in Experiment 2 than in Experiment 1. It is feasible that in Experiment 2 the effect of the prime differed over lags because the overall performance decrement was close to ceiling. Therefore, the interaction may have been due to the fact that the memory task caused a strong performance decrement that was only marginally affected by the addition of the prime. Regardless of this interaction, the most important outcome of the present experiment was the main effect of the prime on T2 performance that was opposite to what the inhibition model would predict when the prime did not have to be inhibited.

All in all, the present findings suggest that the negative effect on T2 performance may be related to NP, although this would not fit the inhibition model. If this is indeed the case, the negative effect then need not depend on whether the prime is physically identical to the target (for a review, see Neill & Mathis, 1998). For instance, NP could also occur when using either pictures or words that are semantically related to the target (Tipper, 1985; Yee, 1991). If the effect observed in Experiments 1 and 2 is based on NP, similar effects should also be observed when using a semantically related rather than an identical prime. To test this assumption, a third experiment was conducted in which, instead of a digit (e.g., 8), a number word (e.g., *eight*) was presented as the prime.

## EXPERIMENT 3
## Semantic Priming

In this experiment, participants observed a prime in the form of a number word that was either the same number as the target (e.g., prime *eight*, target 8) or a different number (e.g., prime *eight*, target 2). T1 and T2 were still presented as single digits. In contrast to Experiment 1, the prime and T2 were not identical but shared the same semantics. This experiment allowed us to investigate the influence of semantic priming on T2 performance.

### Method

The present experiment was identical to Experiment 1, except that a semantic prime was presented as a number word in Dutch (*één*, *twee*, *drie*, *vier*, *zes*, *zeven*, *acht*, and *negen*). Sixteen new students (10 female, 6 male; mean age 20.2 years, age range 17–31) participated in the experiment.

### Results

**T1 accuracy**. T1 was correctly identified on 94% of the trials. For the prime = T2 condition, the performance on lags 1, 2, 3, and 8 was 87%, 94%, 97%, and 97%, respectively. In the same order, the results for the prime ≠ T2 condition were 86%, 96%, 98%, and 98%. There was no significant effect of prime on T1 performance [$F(1,15) = 1.259$, $MS_e = .001$, $p = .280$], but performance did vary significantly across lags [$F(3,45) = 25.833$, $MS_e = .007$, $p < .001$]. Further analysis by means of a two-tailed paired-samples $t$ test showed a significant performance drop on lag 1 as compared with lag 2 [$t(15) = 4.612$, $p < .001$] and on lag 2 as compared with lag 3 [$t(15) = 3.381$, $p < .005$]. No significant two-way interaction between prime and lag was found [$F(3,45) = 1.142$, $MS_e = .001$, $p = .338$].

**T2 accuracy**. The average scores for the individual conditions are shown in Figure 4. The performance on T2 given T1 correct varied with lag [$F(3,45) = 13.595$, $MS_e = .013$, $p < .005$], indicating an AB effect. For T2, there was no significant main effect of prime ($F < 1$) or two-way interaction between prime and lag ($F < 1$).

### Discussion

When the target was primed semantically, no effect on T2 performance was found. These results differ from those of Experiments 1 and 2, in which performance on a primed T2 dropped relative to performance on a nonprimed T2. For an inhibitory effect to occur (as shown in Experiment 1), it seems necessary that the prime be physically identical to the target. Therefore, the present results are not in line with the classic NP explanation referred to as the

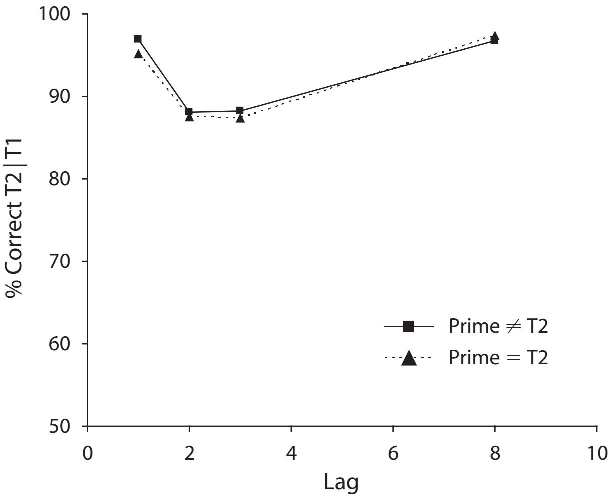


**Figure 4. Results of Experiment 3, in percentages correct, for T2 given T1 correct (T2 | T1) as a function of lag and prime.**

*inhibition model*, as developed by Tipper and colleagues (Houghton et al., 1996; Tipper, 1985; Tipper et al., 1991). However, before excluding NP as an explanation for the performance decrement, a close comparison between the NP and present paradigms is needed.

The paradigm here differs from the classic NP paradigm of Tipper (1985). Typically, the NP paradigm consists of prime and probe trials, each containing a target and a distractor item. NP occurs when an ignored distractor item in the prime trial becomes a target in the probe trial. Still, there are also similarities between the two paradigms. First of all, in both paradigms two targets are presented. This means that T1 in the RSVP stream can be seen as the target in the prime trial and T2 as the target in the probe trial. Second, in both paradigms distractors are present. In addition to the distractors presented in the RSVP stream surrounding T2, the prime presented prior to the RSVP stream could function as a distractor for T1. Note that, in the present experiment, targets and distractors were not presented simultaneously; however, a study by Neill and Mathis (1998) showed that this has no consequences for NP. It could be that the interaction between the prime and T1, both from the same character class, causes the inhibition effect on T2 performance. When T1 and the prime are less related (e.g., are from different character classes), there should be less competition between them, and therefore no reason for the prime to be inhibited.

## EXPERIMENT 4
## Different Character Class Used for T1

In Experiments 1 and 2, the prime, T1, and T2 were all digits. Because all were from the same class of stimuli, the prime could act as a distractor item for T1. To determine whether this was indeed the case, T1 in this experiment was taken from a different character class from that of the prime and T2. If it is true that the prime is suppressed because it competes with T1, we would expect the NP effect to disappear when T1 is from a different character class than are the prime and T2.

## Method

Experiment 4 was similar to Experiment 1, except that instead of digits, the symbols "#" and "%" were used for T1. Participants had to indicate which symbol they had seen by pressing the "z" key for the "#" symbol and the "m" key for the "%" symbol. For T2, the same digits were shown as in the previous experiments, and again participants had to indicate whether the digit was odd or even. During a pilot study, it became clear that this change made the task much easier and that performance on T1 and T2 might reach ceiling. Therefore, the ISI between the items in the RSVP stream was reduced from 80 msec to 40 msec, which made the task equally difficult as the tasks in Experiments 1 and 2. Eight new students (6 female, 2 male; mean age 20.8 years, age range 18–25) participated in the experiment.

## Results

**T1 accuracy**. T1 was correctly identified on 95% of the trials. For the prime = T2 condition, the performance at lags 1, 2, 3, and 8 was 97%, 95%, 93%, and 95%, respectively. In the same order, the results for the prime ≠ T2 condition were 97%, 94%, 95%, and 96%. There was no significant effect of the prime on T1 performance ($F < 1$), but performance did vary significantly with lag [$F(3,21) = 4.441$, $MS_e = .001$, $p < .05$]. Further analysis by means of a two-tailed paired-samples $t$ test showed a significant performance drop at lag 3 as compared with lag 8 [$t(7) = -2.728$, $p < .05$]. No significant two-way interaction was found between prime and lag [$F(3,21) = 1.359$, $MS_e = .001$, $p = .287$].

**T2 accuracy**. The average scores for the individual conditions are shown in Figure 5. T2 given a correct T1 varied with lag [$F(3,21) = 11.133$, $MS_e = .006$, $p < .005$]. Prime had no significant effect on T2 performance ($F < 1$), and the two-way interaction between prime and lag was not significant ($F < 1$).

## Discussion

In contrast to what was found in Experiments 1 and 2, priming of T2 now had no effect on T2 performance. Changing T1 into a symbol apparently made the prime no longer a distractor item for T1, and therefore no additional inhibitory effect was observed. This is in line with the idea that NP occurs when a distractor item is suppressed in favor of the target item in the prime trial (Houghton et al., 1996; Tipper, 1985; Tipper et al., 1991).

Displaying T1 as a symbol did not affect the AB, as shown by the main effect of lag that was still present. However, no typical U shape in the data, a characteristic of the AB, was found. One reason for this may be that the U shape of the AB is based on the time between T1 and T2, and not on the number of lags between the two targets (Martens, Munneke, Smid, & Johnson, 2006). After we sped up the RSVP stream, at lag 8 only 448 msec had passed, instead of the 768 msec in Experiments 1 and 2. Obviously, after 448 msec one would still expect an AB effect.

A minor point of discussion in Experiment 1 was the drop in T1 performance at lag 1. We suggested that this effect could be explained by the fact that the task required a correct order judgment of the targets, which became difficult when targets were presented as close together in time as on lag 1. In the present experiment, no correct order judgment was necessary, because the participants simply knew that a target symbol was presented before a target digit.

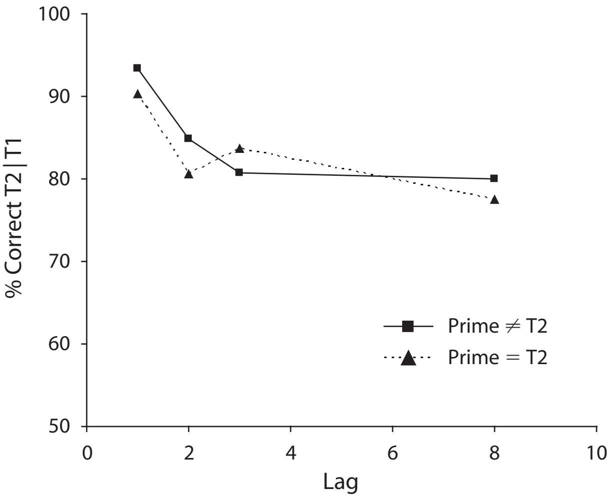


**Figure 5. Results of Experiment 4, in percentages correct, for T2 given T1 correct (T2 | T1) as a function of lag and prime.**

Even though the effect of lag remained significant, post hoc analyses revealed no significant drop in T1 performance at lag 1, which is consistent with the explanation above.

A second objective of the present study was to determine whether the additional inhibitory effect on T2 performance is restricted to the visual domain. In the following experiment, we investigated whether an auditory prime influences the performance for an auditory T2. Such an effect might be expected, because Buchner et al. (2003) found NP effects in the auditory domain when participants had to discriminate between the sounds of animals or of musical instruments.

# EXPERIMENT 5
## Auditory–Auditory Priming

The additional inhibition effect on T2 performance, as shown in Experiments 1 and 2, seems to happen at an early stage of visual processing. This raises the question of whether this effect is specific to the visual domain. To address this issue, participants were presented with a rapid serial auditory presentation (RSAP) stream, comparable to the RSVP stream used in all previous experiments, that was preceded by an auditory prime. The task and design were similar to those of Experiment 1.

## Method

For this experiment, auditory stimuli were used in the form of spoken letters (distractors) and numbers (targets and prime). The letters used as distractors in the RSAP stream were *B*, *C*, *D*, *F*, *G*, *H*, *J*, *K*, *L*, *M*, *N*, *O*, *R*, *U*, *V*, *W*, and *X*. For the prime and targets, the numbers 1, 2, 3, and 4 were used. All letters and numbers were spoken in Dutch by a male voice and were compressed to a duration of 90 msec. Identical auditory stimuli were used for both primes and targets, and prime onset was time-locked 1,500 msec before the onset of the fixation cross. All vocals were digitally recorded and edited with a 16-bit resolution and 44-kHz sampling rate using Cool Edit Pro 2.1 software. During recording, voice inflections were kept to a minimum. The amplitudes of all samples were manually normalized, and time compression was performed by means of a time-stretching routine that manipulated duration without altering pitch.

To make sure that the participants perceived the edited spoken digits correctly, a pilot study was conducted with 4 participants. These participants were presented with an RSAP stream similar to the one used in the experiment, but that contained only one target digit; no prime was presented prior to the stream. The participants then had to give a speeded response by pressing the corresponding number on the keyboard. In this pilot study, all numbers from 1 to 9 were tested; on the basis of the results, the numbers 1 to 4 were selected as the best candidates for the experiment. Nine new students (5 female, 4 male; mean age 21.5 years, age range 18–30) participated in the experiment. All had normal hearing and vision.

### Results

The data of 1 participant were excluded from further analysis because of failure to comply with the task instructions.

**T1 accuracy**. T1 was correctly identified on 84% of the trials. For the prime = T2 condition, the performance on lags 1, 2, 3, and 8 was 83%, 85%, 86%, and 85%, respectively. In the same order, the results for the prime ≠ T2 condition were 81%, 81%, 84%, and 87%. There was no significant effect of prime [$F(1,7) = 2.418$, $MS_e = .002$, $p = .164$] or lag [$F(3,21) = 2.253$, $MS_e = .005$, $p = .146$] on T1 performance, nor was there a two-way interaction between prime and lag ($F < 1$).

**T2 accuracy**. The average scores for the individual conditions are shown in Figure 6. T2 given T1 correct did not vary across lags ($F < 1$), indicating no AB effect. There was a significant effect of prime on T2 performance [$F(1,7) = 8.449$, $MS_e = .002$, $p < .05$], resulting in an overall drop in performance when T2 was primed (86%) as compared with when it was not primed (90%). The two-way interaction between prime and lag was not significant ($F < 1$).

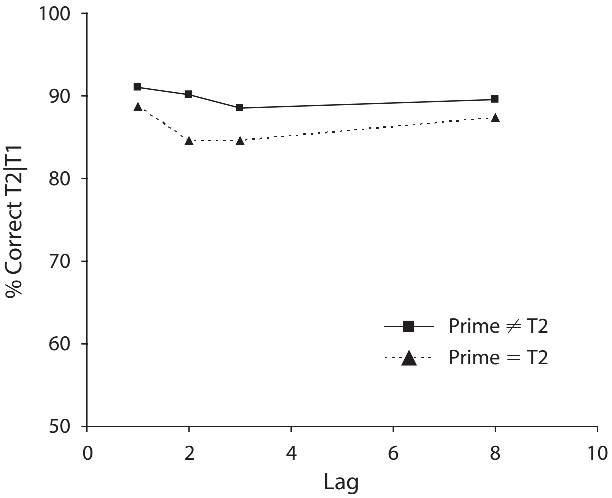


**Figure 6. Results of Experiment 5, in percentages correct, for T2 given T1 correct (T2 | T1) as a function of lag and prime.**

### Discussion

In this experiment, no AB effect was found. This is in line with the results of earlier studies (e.g., Arnell & Jenkins, 2004; Potter, Chun, Banks, & Muckenhoupt, 1998) that have shown that auditory ABs can occur, but not when number targets among letter distractors need to be reported. Nevertheless, we did find an inhibitory effect of the prime on T2 performance, suggesting that the NP effect is not specific to the visual modality. The fact that it occurs in the absence of an AB underlines the idea that NP taps into different resources than does the AB.

Experiments 1, 2, and 5 show inhibitory effects on T2 performance in both the visual and auditory domains. It is well known (see, e.g., Arnell & Jolicœur, 1999; Spence & Driver, 1997) that auditory input can have an effect on processing visual information. Furthermore, Buchner et al. (2003) have demonstrated NP for a prime and a target presented in different modalities. A relevant question, therefore, is whether similar cross-modal inhibitory effects will show up when we use a cross-modal variant of our paradigm.

## EXPERIMENT 6
## Auditory–Visual Priming

Experiment 6 tests whether the inhibitory effects shown in Experiments 1 and 2 (visual) and 5 (auditory) hold in a cross-modal setting in which an RSVP stream is preceded by an auditory prime. If an auditory prime were to influence T2 performance, it could mean that interference takes place between the auditory and visual modalities at an amodal level. If this effect were to yield findings similar to those of Experiments 1 and 2, it would provide additional information concerning the level at which the inhibition we have observed takes place.

### Method

The present experiment was identical to Experiment 1, except that an auditory prime was presented. The prime was a spoken number, delivered in Dutch in a male voice, and was presented by means of Sennheiser HD 202 headphones. The sound samples used had an average duration of 425 msec (16 bits, 44 kHz). The onset of the sound sample was time-locked 1,000 msec before the onset of the fixation cross. The sound samples were manually normalized for amplitude. Twenty-four new students (10 female, 14 male; mean age 20.6 years, age range 15–36) participated in the experiment. All had normal hearing and vision.

### Results

**T1 accuracy**. T1 was correctly identified on 91% of the trials. For the prime = T2 condition, the performance on lags 1, 2, 3, and 8 was 88%, 94%, 94%, and 97%, respectively. In the same order, the results for the prime ≠ T2 condition were 87%, 94%, 95%, and 97%. There was no significant main effect of prime ($F < 1$). The two-way interaction between prime and lag failed to reach significance ($F < 1$), but there was a main effect of lag [$F(3,69) = 28.474$, $MS_e = .004$, $p < .001$]. Further analysis by means of a two-tailed paired-samples $t$ test showed a significant performance drop on lag 1 as compared with lag 2 [$t(23) = 4.459$, $p < .001$] and an increase in performance on lag 8 as compared with lag 3 [$t(23) = 3.551$, $p < .005$].

**T2 accuracy**. The average scores for the individual conditions are shown in Figure 7. The performance on T2 given T1 correct varied with lag [$F(3,69) = 14.534$, $MS_e = .009$, $p < .001$], indicating an AB effect. For T2, there was no significant main effect of prime [$F(1,23) = 2.461$, $MS_e = .003$, $p = .130$]. The two-way interaction between prime and lag was also not significant [$F(3,69) = 1{,}661$, $MS_e = .003$, $p = .204$].

**Discussion**

Unlike in Experiments 1 and 2, the present results do not show a significant effect of the prime on T2 performance. A reason for the observed null result could be that cross-modal priming is simply not possible within this paradigm. Even though earlier reports have shown cross-modal priming (Graf et al., 1985) and cross-modal NP (Buchner et al., 2003), in these studies the stimuli were words and line drawings. In order to find a cross-modal effect, input from different sensory modalities might need to interact on a level at which amodal semantic representations have already formed. In line with the results of our Experiment 3, the present study confirms that priming at a semantic level does not cause a negative effect on T2 performance.

## GENERAL DISCUSSION

This study began with the premise that in an AB task, priming T2 with an identical item has an inhibitory effect on T2 performance. Both Experiments 1 and 2 showed this effect and revealed that this effect adds to the classic AB effect. Similar effects were reported in earlier studies (Akyürek & Hommel, 2005; Nieuwenstein et al., 2007). One of our conjectures was that this effect might be the result of NP. If this is indeed the case, one would expect the effect to disappear when T1 was from a different character class than the prime and T2. Indeed, one can argue that when no competition between prime and T1 takes place, there is no need for inhibition. Our Experiment 4 confirmed this prediction by showing that the inhibitory effect of the prime disappears when T1 is changed. In addition, we wanted to determine whether this inhibitory effect would also occur during unimodal auditory priming and during auditory–visual cross-modal priming. Experiment 5 indeed showed an auditory priming effect when T2 was also presented auditorily. However, cross-modal (auditory–visual; Experiment 6) priming had no effect on T2 performance.

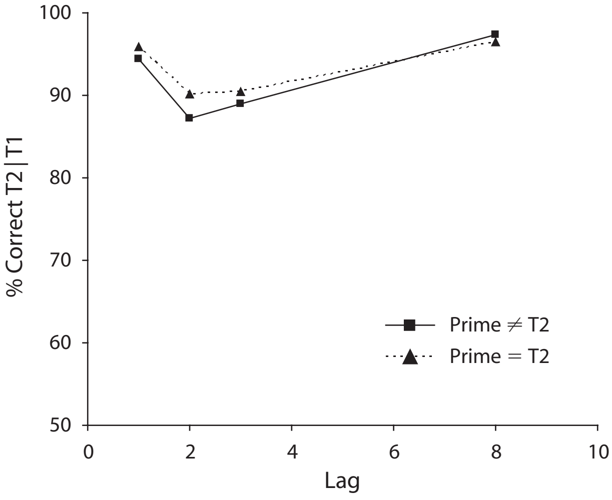


**Figure 7. Results of Experiment 6, in percentages correct, for T2 given T1 correct (T2 | T1) as a function of lag and prime.**

The results of Experiments 1, 2, and 5 are consistent with those from previous studies (Akyürek & Hommel, 2005; Nieuwenstein et al., 2007) that have shown similar inhibitory effects on T2 performance when this target is preceded by an item that is identical or from a similar character class. The fact that the semantic primes used in Experiments 3 and 6 did not influence T2 performance suggests that the observed inhibition takes place before a semantic level is reached. There are several ways to interpret this unimodal inhibitory priming effect.

The idea that identical items presented in different tasks during the same trial are harder to retrieve than items used in a single task was named "cross-talk repetition amnesia" by Nieuwenstein et al. (2007). In their study, an STM set was presented prior to a standard AB task. When an STM item was identical to one of the AB targets, performance for these targets decreased. According to the idea of cross-talk repetition amnesia, both the STM item and the targets in the AB task go through a "tokenization" process in which binding between episodic features and item representations takes place. When an item is stored with episodic features from different tasks, retrieval of this item causes interference between these episodic features, and this interference can result in errors during retrieval. Our results indicate that it is not necessary to use a whole STM set; a single prime can also evoke such errors. In other words, no cross-talk between tasks is needed in order to observe inhibition on T2 performance; a mere single item that does not have to be retrieved will have the same effect. One could argue that looking at the prime can be seen as a separate task, in which case the idea of cross-talk repetition amnesia is still valid. In a more general way, our results show that an interaction occurs between items perceived prior to an AB task and identical items that are part of the RSVP stream, and that this interference does not have to take place during the retrieval period (as the notion of cross-talk repetition amnesia suggests) but could also take place during consolidation of T2. Still, the basic mechanism behind this effect needs to be explained. We reported earlier that the idea of cross-talk repetition amnesia is in line with the episodic retrieval model of NP.

In our Experiment 2, episodic retrieval still cannot be ruled out as a possible explanation. Note that in this experiment the prime was shown for 1.5 sec and that the participants sometimes had to report it. In these prime recall trials, the response to the prime differed from the responses to the targets (T1 and T2) in the other trials. For the prime, participants had to indicate whether or not the prime was similar to a test number, whereas for a target they had to indicate whether it was an odd or even digit. In line with Neill and Mathis (1998), one could argue that the episodic retrieval model holds for this experiment, assuming that the prime and the targets were processed differently; even though both prime and targets would have been stored with a "respond to" tag, the different types of response ("same as" rather than "odd" or "even") would have been stored as well. This difference could explain the NP effect that we found. However, Experiment 4 showed no NP effect when T1 was from a different character class than the prime and T2. According to the episodic retrieval model, NP should still have occurred in this case, because the prime and T2 required different responses. This means that the episodic retrieval model can offer only a partial explanation of our results.

According to the inhibition model, on the other hand, NP seems to operate as a postselection mechanism on a central semantic level and can be influenced by participants' strategies (see May, Kane, & Hasher, 1995, for a review). Both auditory and visual, as well as cross-modal, priming can occur (Buchner et al., 2003), making this account a possible explanation for the inhibitory effects of unimodal priming observed on T2 performance (Experiments 1, 2, and 5). However, as noted earlier, the results from Experiment 2 were not in line with the idea of the inhibition model of NP, which predicts facilitation effects for actively observed primes. Moreover, the results of Experiment 3 showed no effect of semantic priming, and those of Experiments 1 and 2 indicated that participants' strategies have basically no influence. Nevertheless, we also found evidence that inhibition of the prime underlies the drop in T2 performance observed in our experiments. In Experiment 4, we determined whether a prime presented prior to the RSVP stream functioned as a distractor item for T1. When we changed the character class of T1, the inhibitory effect disappeared. This finding supports the notion that we indeed were seeing an effect of NP. However, in light of the results of our other experiments, we cannot conclude that the inhibition model is able to adequately explain this NP, because the model seems to be based on inhibitory processes that take place at a higher level than those that played a role in the effects observed here.

To summarize, the interference found in this study seems to act on a feature extraction level, rather than on a semantic level as reported in earlier studies. In the present AB task, we found unimodal NP effects on T2 performance in both the auditory and visual modalities, but no cross-modal or semantic influences. For this effect to occur, prime and target needed to be identical, both needed to be presented in the same modality, and the target had to be accompanied by another target from the same character class.

## AUTHOR NOTE

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